9.0 POST-INJECTION SITE CARE AND SITE CLOSURE PLAN
40 CFR 146.93(a)

MARQUIS BIOCARBON PROJECT

Facility Information

Facility name:	MARQUIS BIOCARBON PROJECT
Facility contact:	ELIZABETH STEINHOUR DIRECTOR OF ENVIRONMENTAL AFFAIRS 10000 MARQUIS DRIVE, HENNEPIN, IL 61327 815.925.7300 / BETHSTEINHOUR@MARQUISENERGY.COM
Well name:	MCI CCS 3
Well location:	PUTNAM COUNTY, ILLINOIS S2 T32N R2W Latitude: 41.27026520 N, Longitude: 89.30939322 W

Table of Contents

List of Tables

List of Figures

9.0 Post-Injection Site Care and Site Closure (PISC) Plan

9.1 Introduction

This Post-Injection Site Care and Site Closure (PISC) plan describes the activities that Marquis Carbon Injection LLC will perform to meet the requirements of 40 CFR 146.93. Marquis Carbon Injection LLC will monitor groundwater quality and track the position of the carbon dioxide (CO_2) plume and pressure front for 5 years after the cessation of injection, which is the anticipated timeline for CO_2 plume and pressure front stabilization.

9.2 Pre- and Post-Injection Pressure Differential [40 CFR 146.93(a)(2)(i)]

Based on the modeling of the pressure front as part of the area of review (AoR) delineation, pressure at the MCI CCS 3 well is expected to decrease to pre-injection levels in less than 5 years, as described below. Additional information on the projected post-injection pressure declines and differentials is presented in the permit application and the AoR and Corrective Action Plan (Permit Section 2).

Figure 9-1 shows the modeling results of pressure behavior during the injection phase of the project and a 50-year post-injection period for Layer 153 within the computational model which is used to delineate the AoR for the project. Refer to the AoR and Corrective Action Plan (Permit Section 2) for more information on the delineation of the AoR. In the post injection phase, pressures at the MCI MW 2 and MCI CCS 3 (monitoring and injection) wells decrease to pre-injection levels in less than 5 years.

Non-Responsive; Agreed Upon Omission

[redacted]

Figure 9-1: Pressure predictions at the MCI CCS 3 well based on Layer 153 with an elevation of 3,833 TVDSS, ft from the computation model for the 5-year injection phase and a post injection period of 50 years.

9.3 Predicted Position of the CO_2 Plume and Associated Pressure Front at Site Closure (40 CFR 146.93(a)(2)(ii))

Figure 9-2 shows the predicted extent of the CO_2 plume at the end of the PISC timeframe that represents the maximum extent of the CO_2 plume in relation to the AoR. This map is based on the final AoR delineation modeling results submitted pursuant to 40 CFR 146.84.

Figure 9-3 shows the predicted extent of the CO_2 plume at the end of the injection phase and at 3 and 5 years after the cessation of injection. The figures demonstrate the stability of the CO_2 plume during the PISC phase. Figure 9-4 shows a cross section of the pressure buildup around the MCI CCS 3 well at the end of the injection phase and at 3 and 5 years after the cessation of injection using a pressure build-up cut-off of 150 pounds per square inch (psi) to delineate the pressure front. The pressure front decreases rapidly after the injection period ends and decreases to the pre-injection pressure in less than 5 years.

Non-Responsive; Agreed Upon Omission

[redacted]

Figure 9-2: Map showing the modeled CO_2 plume footprint, AoR, and existing and proposed project wells within the AoR.

Non-Responsive; Agreed Upon Omission

[redacted]

Figure 9-3: Cross section of the CO_2 plume at the end of the injection phase and at 3 and 5 years after the cessation of injection.

Non-Responsive; Agreed Upon Omission

[redacted]

Figure 9-4: Predicted pressure plume response at the end of the injection phase and after 1, and 5 years after the cessation on injection. The pressure build-up cut-off is 150 psi.

9.4 Post-Injection Monitoring Plan (40 CFR 146.93(b)(1))

Performing groundwater monitoring, storage zone pressure monitoring, and geophysical monitoring as described in the following sections during the post-injection phase will meet the requirements of 40 CFR 146.93(b)(1). The results of all post-injection monitoring will be submitted semi-annually in Year 1 of the PISC and annually in subsequent years.

A quality assurance and surveillance plan (QASP) for all testing and monitoring activities during the injection and post-injection phases is provided in Appendix 7.A of the Testing and Monitoring Plan (Permit Section 7).

Table 9-1 summarizes the monitoring activities that will take place during the PISC phase of the project. The project will continue to monitor the well integrity of the MCI CCS 3 and MCI MW 2 wells on a yearly basis using temperature measurements to ensure that there is no migration of CO_2 up the wellbores. In addition, the annular pressures and fluid volumes in the MCI CCS 3 well will be monitored on a continuous basis until the well is plugged and abandoned. Annular pressure in the deep monitoring well will be monitored daily until the well is plugged and abandoned. Refer to the Well Operations Plan and the Testing and Monitoring Plan for more information on the well integrity and operational monitoring plans (Permit Sections 6 and 7, respectively).

Pulsed neutron capture (PNC) logging will continue in the MCI MW 2 well and the above confining zone (ACZ) monitoring well (MCI ACZ-1) in the second quarter of each year of the PISC phase. This will allow the project to continue to characterize the vertical plume development in the Mt. Simon Sandstone in the MCI MW 2 well and further verify that CO_2 is not migrating past the confining zone and into the ACZ aquifers, thereby endangering underground sources of drinking water (USDWs). Refer to the Testing and Monitoring Plan for more information on the PNC logging plans in the injection phase of the project (Permit Section 7).

The project will continue to monitor pressures within the Mt. Simon Sandstone in the MCI MW 2 well and pressure at the top of the Mt. Simon Sandstone in the MCI CCS 3 well until it is abandoned. The pressure within the Mt. Simon Sandstone is expected to begin to dissipate once CO_2 injection ceases based on the computational modelling. The Mt. Simon Sandstone pressure measurements are expected to verify the pressure decrease, and the data will be used to history match the computational modelling in the PISC phase.

Monitoring Activity	PISC Frequency*	Location	Depth Range (ft, MD)
Assurance Monitoring:			
Shallow Groundwater Sampling	Twice/year	GW-1, 2, 3 & 4 wells within AoR	Producing zone
Isotope Analysis	Twice/year	GW-1, 2, 3 & 4 wells within AoR	0 – TD
Operational Monitoring:			
Annular Pressure	Continuous	MCI CCS 3 well	Surface
Annular Fluid Volume	Continuous	MCI CCS 3 well	Surface
Annular Pressure	Daily	MCI MW 2 well	Surface
Temperature Measurement	Annually Annually	MCI CCS 3 well MCI MW 2 well	0 – TD 0 – TD
Verification Monitoring:			
Fluid Sampling			
Gunter Sandstone Galesville Sandstone Upper Mt. Simon Sandstone	Twice/year Twice/year Twice/year	MCI ACZ 1 well MCI ACZ 1 well MCI MW 2 well	2,134 2,651 3,110
Isotope Analysis	Twice/year	MCI ACZ 1 well MCI MW 2 well	All samples
Pressure – Temperature Sensors			
Gunter Sandstone Galesville Sandstone Upper Mt. Simon Sandstone	Continuous Continuous Continuous	MCI ACZ 1 Well MCI ACZ 1 Well MCI MW 2 well	2,134 2,651 3,100
PNC Logging	Once/ year	MCI MW 2 well MCI ACZ 1 well	2,134 – TD 2,134 – TD
Microseismic Monitoring	Continuous	Surface stations	TBD
Time-lapse 3D Surface Seismic Data	Every 5 years and as required.	Surface	

Table 9-1: Summary of monitoring activities in the PISC phase of the project.

Pressures will also continue to be monitored in the Galesville Sandstone and the deepest USDW to confirm the continued containment of CO_2 within the storage formation (Figure 9-5). Fluid samples will be taken from the Galesville Sandstone and deepest USDW once a year for geochemical and isotopic analysis to further verify CO_2 containment. Shallow groundwater fluid samples will also be obtained each year from the shallow groundwater wells, MCI GW 1-4, for geochemical and isotopic analysis.

Microseismic activity is expected to return to background (pre-injection) levels once the injection phase of the project is complete and the associated pressure plume begins to dissipate. The microseismic monitoring would then be phased out in the first six to twelve months of the PISC phase. This will be evaluated in the first months of the PISC phase of the project, and no decisions will be made without consultation with the Underground Injection Control (UIC) Program Director (UIC Director).

The project proposes to acquire two time-lapse three-dimensional (3D) surface seismic surveys in the PISC phase of the project. One will be acquired within one year of the end of the injection phase or at the start of the PISC phase of the project. The final survey will be acquired in the final year of the PISC phase of the project. The objectives of these two surveys include:

- Verification of continued CO_2 containment in the storage formation
- Demonstration of the stability of the CO_2 plume after the injection phase of the project
- Providing data for the calibration and verification of the computational modelling

These data will be used to demonstrate non-endangerment of USDWs at the end of the PISC phase (Section 5.0).

Marquis companies own the land on which the injection, deep monitoring, and ACZ wells are located. Marquis also owns the land on which the shallow groundwater wells used for monitoring are located. The wells are on flat farmland not near residential areas. Access to the wells is not anticipated to be an issue for the PISC phase of the project.

Non-Responsive; Agreed Upon Omission

[redacted]

Figure 9-5: Stratigraphic column from MCI MW 1 well located at the Marquis BioCarbon Project site.

9.4.1 Monitoring Above the Confining Zone

The monitoring plan for the PISC is designed to be adaptive and respond to evolving project risks over time. At this point in the project, no phased monitoring has been planned for the MCI ACZ 1 well; however, this may be assessed later as the project progresses. No changes will be made to the PISC without informing the UIC Director (40 CFR 146.93 (a)(3)).

Table 9-2 presents the proposed MCI ACZ 1 and groundwater monitoring wells monitoring methods, locations, and frequencies. For fluid sampling, a bailer system or like method that maintains the formation pressure of the sample will be used to collect water samples to be analyzed for dissolved inorganic carbon, alkalinity, pH, and isotopic parameters. Samples for all other analytes will be collected with an open-ended bailer. Prior to sample collection the well will be swabbed to remove stagnant water and ensure representative water is collected from the formation. The fluid swabbed from the well will be monitored for field parameters, such as pH, specific conductance, and temperature, using a calibrated water quality meter (Horiba U-53, or similar). Once these parameters stabilize, it will be an indication that representative formation fluid is in the well at the time the sample is collected.

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
Shallow Groundwater	Groundwater geochemistry and stable isotopes	Select Shallow groundwater wells in AoR	88 – 246 ft, MD	Q2/ year after injection ceases
Gunter Sandstone	Groundwater geochemistry and stable isotopes	MCI ACZ-1	TBD	Q2/ year after injection ceases
Galesville Sandstone	Groundwater geochemistry and stable isotopes	MCI ACZ-1	~2,670 ft, MD	Q2/ year after injection ceases
Galesville Sandstone	PNC Logging	MCI ACZ-1	2,500 – 2,800 ft, MD	Q2/ year after injection ceases

Table 9-2: Monitoring of ground water quality and geochemical changes above the confining zone.

Table 9-3 identifies the initial groundwater parameters to be monitored and the analytical methods that will be used for the samples in the baseline analysis of the data. During the pre-injection and injection phases, the project will assess which subset of analytes are most responsive to interactions with CO_2, so the list of analytes will be reduced in the future (Permit Section 7). However, no changes will be implemented without consultation with the UIC Director.

Parameters	Analytical Methods
Cations (Na, Ca, Mg, Ba, Sr, Fe, K)	ASTM D1976
Anions (Cl, Br, SO_4)	ASTM D4327
pH	ASTM D1293
Alkalinity	ASTM D3875
Total Dissolved Solids (TDS)	ASTM D5907
Density	ASTM D4052
Dissolved Inorganic Carbon	ASTM D513-11
Conductivity/Resistivity	ASTM D1125
Stable Isotopes of C, O, and H	ASTM STP 573
Carbon-14	

Table 9-3: Summary of analytical and field parameters for ground water samples.

A nationally certified laboratory will be selected for the groundwater sampling and analysis. The sampling and analytical measurements will be performed in accordance with project quality assurance requirements. Samples will be tracked using appropriately formatted chain-of-custody forms. See the QASP for additional information (Permit Section 7, Appendix 7.A).

The results of the geochemical and isotope analysis will be delivered in the form of laboratory reports. If anomalous changes in the aqueous geochemistry are observed in the ACZ monitoring zones, new samples will be obtained from the affected aquifer and sent for analysis to verify the changes.

If anomalous changes are confirmed (greater than 5% deviation from baseline values as described in the Testing and Monitor Plan [Section 7.5]), the frequency with which fluid samples are obtained from the ACZ aquifers for analysis will be increased. As a precautionary measure, the fluid sampling frequency for the shallow groundwater monitoring wells will also be increased in consultation with the UIC Director. If the injected CO_2 has a unique isotopic signature from the existing isotopes in the overlying aquifers, a new round of samples will be collected for isotopic analysis from the affected aquifer. Confirmed anomalous changes may also trigger the need for additional well integrity testing in both the MCI MW 2 well and the MCI CCS 3 well to ensure that no well integrity issues have developed since the last set of external mechanical integrity tests. A combination of anomalous pressure, geochemical, and well integrity testing results may result in the decision to acquire a time-lapse surface seismic survey before the survey scheduled in year five of the PISC to determine the size of the leakage accumulation (Table 9-1).

Table 9-4 presents information about the continuous monitoring devices to be used in the deepest USDW and the Galesville Sandstone. The pressure/temperature data will be stored as time stamped data pairs. Migration of CO_2 or brine into the MCI ACZ 1 well will likely first be identified through pressure changes in the aquifers. An increasing pressure trend in either aquifer would suggest that leakage across the confining layer is occurring. While any increasing trend in pressure or temperature will be evaluated, an increase in pressure or temperature greater than 5% above baseline values will warrant additional monitoring and inspections to rule out the possibility of fluid leakage out of the storage formation. Such an increase in pressure or temperature would initiate more frequent fluid sampling and analysis for geochemical parameters from the aquifer with the pressure/temperature increase. An increase in pressures or temperatures in the MCI ACZ 1 well may also trigger additional external well integrity investigations in the MCI CCS 3 or MCI MW 2 well.

Parameter	Device(s)	Location	Min. Sampling Frequency	Min. Recording Frequency
Pressure	Pressure Gauge	Deepest USDW Galesville Sandstone	Every 1 min.	Every 1 min.
Temperature	Temperature Gauge	Deepest USDW Galesville Sandstone	Every 1 min.	Every 1 min.

Notes:

- Sampling frequency refers to how often the monitoring device obtains data from the well for a particular parameter. For example, a recording device might sample a pressure transducer monitoring injection pressure once every two seconds and save this value in memory.
- Recording frequency refers to how often the sampled information gets recorded to digital format (such as a computer hard drive). For example, the data from the injection pressure transducer might be recorded to a hard drive once every minute.

Table 9-4: Sampling and recording frequencies for continuous monitoring in the MCI ACZ 1 well.

9.4.2 CO_2 Plume and Pressure Front Tracking (40 CFR 146.93(a)(2)(iii))

Marquis Carbon Injection LLC will employ direct and indirect methods to track the extent of the CO_2 plume and the presence or absence of elevated pressure.

Table 9-5 presents the direct and indirect methods that will be used to monitor the CO_2 plume including the activities, locations, and frequency of sampling.

Fluid sampling will be performed as described in Section B.2 of the QASP; sample handling and custody will be performed as described in B3 of the QASP; and quality control will be ensured using the methods described in B5 of the QASP. Quality assurance procedures for seismic monitoring methods are presented in B9 of the QASP (Permit Section 7, Appendix 7.A).

Target Formation	**Monitoring Activity**	**Monitoring Location(s)**	**Spatial Coverage**	**Frequency**
Direct Plume Monitoring				
Galesville, Eau Shale, and Mt. Simon Formations	Pulsed Neutron Logging	Deep monitor well	2,600 – 4,800 ft, MD	Q2/ Year
Indirect Plume Monitoring				
Galesville, Eau Shale, and Mt. Simon Formations	Time-lapse 3D Surface Seismic Data	Over project AoR	To be confirmed prior to survey	Q2, Year 1 Q2, Year 5

Table 9-5: Post-injection phase CO_2 plume monitoring.

The PNC logs will be received as log ascii standard (LAS) files and interpreted products that can be imported into the static earth model (SEM). PNC logging will be used to monitor the distribution and saturation of CO_2 adjacent to the wellbore in the MCI MW 2 well. The PNC logs will be acquired through the Galesville Sandstone in the MCI MW 2 well to confirm the absence of CO_2 accumulations along the wellbores above the confining layer. Technical details on PNC logging tools can be found in the QASP (Permit Section 7, Appendix 7.A).

Surface seismic data are delivered in a variety of formats including acquisition and processing reports and raw data files from a variety of points in the processing flow. In the context of time-lapse analysis, an assessment will be provided on the differences between the baseline and time-lapse surveys as well as data files that can be incorporated into the SEM. The injection of CO_2 and expansion of the plume is expected to change the acoustic impedance of the Mt. Simon Sandstone over time. These acoustic impedance changes will be used to track the CO_2 plume during the PISC phase of the project. The time-lapse surface seismic data will also be monitored for changes that may suggest that CO_2 has migrated past the confining layer.

Table 9-6 presents the direct and indirect methods that will be used to monitor the pressure front. The pressure/temperature sensors will be programmed to measure and record pressure and temperature readings every 60 sec. The gauges will be retrieved for data download on a quarterly basis. A pair of gauges will be placed in each zone to limit the possibility of data loss. The final monitoring interval in the upper Mt. Simon Sandstone will be determined after the MCI CCS 3 well has been drilled and the well logs have been analyzed (Pre-Operational Testing Program, Permit Section 5). Two pressure sensors will also be set at the MCI CCS 3 well to measure the pressure fall-off at the top of the Mt. Simon Sandstone until the well is abandoned. The pressure/temperature data will be stored as time-stamped data pairs that can used for history matching in the computational model.

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
Direct Pressure-Front Monitoring				
Upper Mt. Simon Sandstone	Pressure Monitoring	MCI MW 2	3,100 – 3,500 ft, MD Exact TBD	Continuous
Top Mt. Simon Sandstone	Pressure Monitoring	MCI CCS 3 well	3,100 ft, MD	Continuous
Indirect Pressure-Front Monitoring				
Eau Claire and Mt. Simon Formations, and Precambrian Basement	Microseismic Monitoring	5 Surface Stations	AoR	Continuous

Table 9-6: Post-injection phase pressure-front monitoring.

The results of the geochemical and isotope analysis, PNC logging, and time-lapse 3D surface seismic data will all be integrated to develop a comprehensive understanding of the CO_2 plume development over time. PNC logging and time-lapse 3D surface seismic data can be incorporated into the SEM for comparison to the computational modelling predictions at different points in time. Based on the current computational modelling results, the CO_2 plume is predicted to stabilize (Figure 9-3), and the pressure plume is predicted to rapidly decrease to pre-injection levels within the proposed 5-year PISC phase. Time-lapse 3D surface seismic surveys acquired during Year 1 and Year 5 of the PISC phase will characterize the stabilization of the CO_2 plume. The pressure data from the MCI MW 2 and MCI CCS 3 wells will verify the decline in formation pressures predicted by the computational modelling.

The increase in pressure in a storage formation is one of the primary drivers for CO_2 and brine migration beyond the confining layer and potentially endangering USDWs. The rapid decrease in pressure in the Mt. Simon Sandstone coupled with the ACZ monitoring and absence of evidence for CO_2 migration beyond the confining layer will demonstrate the non-endangerment of USDWs within the AoR (Section 9.5).

9.4.3 Schedule for Submitting Post-Injection Monitoring Results (40 CFR 146.93(a)(2)(iv))

All PISC monitoring data and results collected using the methods described above will be submitted in reports to the EPA. In the first year of the PISC phase, reports will be submitted on a semi-annual basis. After the first year of the PISC phase, reports will be submitted annually. The reports will contain information and data generated during the reporting period (i.e., well-based monitoring data, sample analysis, and the results from updated site models). The initial Year 1 report will be submitted within eight months after the date that injection stops or alternatively on a data agreed upon with the UIC Director.

9.5 Alternative Post-Injection Site Care Timeframe (40 CFR 146.93(c))

Marquis Carbon Injection LLC will conduct post-injection monitoring for a five-year period following the cessation of injection operations. A justification for this alternative PISC timeframe is provided below.

9.5.1 Computational Modeling Results – 40 CFR 146.93(c)(1)(i)

Figure 9-3 shows the cross section of the predicted CO_2 plume extent and demonstrates the CO_2 plume stability during alternative PISC timeframe. Figure 9-4 illustrates a cross section of the predicted pressure front during the post-injection period. The pressure front declines quickly during the post-injection period. Figure 9-1 shows, the predicted pressure at the MCI CCS 3 well reaches pre-injection pressure in less than the proposed 5-year PISC timeframe. Given the fast CO_2 plume stabilization and rapid pressure decrease in the Mt. Simon Sandstone predicted by the computational modeling, a 5-year PISC is appropriate to ensure USDW protection.

This was further supported by a sensitivity analysis to test the effects of varying the porosity and permeability relationships on the CO_2 plume shape and pressure behavior (Figures 9-6 and 9-7). High side and low side case runs, testing two porosity permeability relationships in addition to the base case were performed. The permeability vs porosity plot for each case in the Mt Simon is shown Figure 9-6. The results of the sensitivity analysis indicate that the CO_2 plume shape is similar in both cases compared to the base case scenario (Figure 9-7). Details related to this sensitivity analysis are discussed further in AoR and Corrective Action Plan Section (Permit Section 2.6.7).

Non-Responsive; Agreed Upon Omission

[redacted]

Figure 9-6: Plot of porosity and permeability relationships for High Side Case (orange line) and Low Side Case (blue line). The numbers on the orange are permeability values, number on the blue line are porosity values. The porosity permeability relationship for the base case was calculated from the ratio between permeability and porosity at the intersection of the curves.

Non-Responsive; Agreed Upon Omission

[redacted]

Figure 9-7: CO_2 plume at layer 153 (used to delineate AoR) at the end of injection, 1, 5 and 10 years after injection stopped for the High Side Case (top row) and Low Side Case (bottom row).

9.5.2 Predicted Timeframe for Pressure Decline – 40 CFR 146.93(c)(1)(ii)

Figure 9-4 shows the cross section of the pressure front during the post injection phase. Additional plots and figures, showing the pressure front during the injection period, can be found in the AoR and Corrective Action Plan Section (Permit Section 2). The maximum spatial extent of the pressure front occurs at the end of the injection period. Figure 9-1 shows the predicted pressure buildup and decline at the MCI CCS 3 well through the injection phase and for 50 years of the post-injection period. The pressure declines immediately following cessation of injection and is predicted to be heterogenous between the MCI CCS 3 and MCI MW 2 wells (Figure 9-1). The details related to sensitivity analysis can be found in the AoR and Corrective Action Plan Section (Permit Section 2). A comparison of the pressure time series from the sensitivity analysis demonstrates that the pressure buildup during the injection phase and rapid decline during the PISC phase are similar to the base case scenario for different porosity permeability relationships (Figure 9-8).

Continuous pressure measurements will be acquired from the Mt. Simon Sandstone through the injection and PISC phases of the project (Testing and Monitoring Plan, Permit Section 7). The pressure data obtained during the injection phase of the project will be used to update the computational modelling every six months as per the reporting requirements in 40 CFR 146.91. Pressure data acquired during the PISC phase of the project are expected to verify the rapid decline in pressure in the Mt. Simon Sandstone predicted by the computational modelling.

9.5.3 Predicted Rate of Plume Migration – 40 CFR 146.93(c)(1)(iii)

Figure 9-3 shows the cross section of the CO_2 plume remains relatively stable from the end of the injection period to Year 3 and Year 5 of the PISC phase. Additional figures illustrating the predicted CO_2 plume expansion during the injection period are provided in the AoR and Corrective Action Plan Section (Permit Section 2). The average CO_2 plume extent was utilized to define the AoR. The details related to sensitivity analysis are presented in the AoR and Corrective Action Plan Section (Permit Section 2.6.7). The results from the sensitivity analysis show that the CO_2 plume shape remains a similar or smaller size and shape for the different modeled porosity permeability relationships (Figure 9-7).

9.5.4 Confining Zone Characterization – 40 CFR 146.93(c)(1)(vii)

The Eau Claire Formation is the primary confining unit for the project. The base of the Eau Claire Formation is comprised of the sandy Elmhurst Member where some CO_2 mobility is expected over time. However, the Eau Claire Formation has known thick and continuous shale intervals (Eau Claire Shale) above the Elmhurst Member, which have been confirmed as having good sealing capacity with core analysis (Permit Section 5). The Pre-Operational Testing Plan details the characterization that has been completed for the Eau Claire Shale (Permit Section 5).

This included assessing the mineralogy, geomechanics, and capillary pressure within the Eau Claire Shale.

The properties of the Eau Claire Formation were distributed within a static reservoir model and then imported into the computational model. Figure 9-3 shows the cross section of the plume map at the end of the injection period and for Years 3 and 5 of the PISC phase. Additional figures illustrating the CO_2 plume behavior during a 50-year post-injection period have been included in the AoR and Corrective Action Plan Section (Permit Section 2). Computational modeling results show that there would be no CO_2 penetration into the Eau Claire Shale during the injection and post-injection modeling period due to the low permeability of the Eau Claire Shale.

9.5.5 Assessment of Fluid Movement Potential – 40 CFR 146.93(c)(1)(viii)-(ix)

There is no evidence of geological conduits within the AoR. Also, within the AoR there are no existing wells that penetrate either the injection zone or the confining layer, so no corrective action is required.

The MCI CCS 3 well will be constructed according to the USEPA Class VI regulations, and several measures will be incorporated in the well design to ensure protection of the USDWs at the site following the injection period (Injection Well Construction Plan, Permit Section 4). The long casing string and packer will be constructed of corrosion-resistant alloys (CR13) across the injection reservoir and confining zone to reduce the chances of casing degradation over the long term. Similarly, a CO_2-resistant cement will be pumped behind the deep string casing across the injection reservoir and confining zone. Following completion of the injection phase of the project and monitoring efforts, the MCI CCS 3 well will be plugged and abandoned according to the EPA Class VI guidelines, including the use of CO_2-resistant cement across the storage formation (Injection Well Plugging Plan, Permit Section 8).

During the injection and PISC phases of the project, the well integrity of the MCI CCS 3 and MCI MW 2 wells will be monitored through several internal and external monitoring techniques (Section 9.3, Permit Section 7). Annular pressures and fluid volumes will be monitored in the MCI CCS 3 well on a continuous basis until the MCI CCS 3 well is abandoned. Annular pressures in the MCI MW 2 well will be monitored daily. Temperature logging is the primary external mechanical integrity test that will be used to monitor the MCI CCS 3 and MCI MW 2 wells on an annual basis.

9.5.6 Location of USDWs – 40 CFR 146.93(c)(1)(x)

At the Marquis BioCarbon Project site, the Mt. Simon Sandstone is not considered a USDW based on salinity samples acquired from MCI MW 1 with total dissolved solids (TDS) concentrations greater than 10,000 milligrams per liter (mg/L) or 10,000 parts per million (ppm).

The lowermost USDW is defined locally as the Gunter Sandstone of the Prairie du Chien Group (Knox Supergroup). At the MCI MW 1 well, the base of the Gunter Sandstone is 963 feet (ft) above the top of the Mt. Simon. USDWs in the project site range from the Gunter Sandstone (deepest USDW) to shallow, near-surface glacial till aquifers.

9.6 Non-Endangerment Demonstration Criteria

Prior to approval of the end of the post-injection phase, Marquis Carbon Injection LLC will submit a demonstration of non-endangerment of USDWs to the UIC Director, per 40 CFR 146.93(b)(2) and (3).

The owner or operator will issue a report to the UIC Director. This report will make a demonstration of USDW non-endangerment based on the evaluation of the site monitoring data used in conjunction with the project's computational model. The report will detail how the non-endangerment demonstration evaluation uses site-specific conditions to confirm and demonstrate non-endangerment. The report will include all relevant monitoring data and interpretations upon which the non-endangerment demonstration is based, model documentation and all supporting data, and any other information necessary for the UIC Director to review the analysis. The report will include the following sections:

9.6.1 Introduction and Overview

A summary of relevant background information will be provided, including the operational history of the injection project, the date of the non-endangerment demonstration relative to the post-injection period outlined in this PISC and Site Closure Plan, and a general overview of how monitoring and modeling results will be used together to support a demonstration of USDW non-endangerment.

9.6.2 Summary of Existing Monitoring Data

A summary of all previous monitoring data collected at the site, pursuant to the Testing and Monitoring Plan (Permit Section 7) and this PISC and Site Closure Plan, including data collected during the injection and post-injection phases of the project, will be submitted to help demonstrate non-endangerment. Data submittals will be in a format acceptable to the UIC Director [40 CFR 146.91(e)], and will include a narrative explanation of monitoring activities, including the dates of all monitoring events, changes to the monitoring program over time, and an explanation of all monitoring infrastructure that has existed at the site. Data will be compared with baseline data collected during site characterization [40 CFR 146.82(a)(6) and 146.87(d)(3)].

9.6.3 Summary of Computational Modeling History

The results of computational modeling used for AoR delineation and for demonstration of an alternative PISC timeframe will be compared to the monitoring data collected during the injection and PISC phases of the project. The monitoring data used to update and calibrate the computational modeling and to demonstrate non-endangerment of USDWs will include:

- Pressure monitoring data from the Mt. Simon Sandstone, Galesville Sandstone, and the deepest USDW
- Microseismic data
- PNC logs that characterize CO_2 saturations and vertical plume development along the well bores
- Time-lapse 3D seismic data

Data generated during the PISC period will be used to help show that the computational model accurately represents the storage site and can be used as a proxy to determine the CO_2 and pressure plume's properties and size. Marquis Carbon Injection LLC will demonstrate this degree of accuracy by comparing the monitoring data obtained during the PISC period against the model's predicted properties such as plume location, rate of movement, and pressure decay. The validation of the computational model with the large volume of available data will be a significant element to support the non-endangerment demonstration. The validation of the computational modeling results over the areas and zones where monitoring data have been collected will help to ensure confidence in those areas of the model where surface infrastructure precludes the collection of time-lapse 3D surface seismic data or the installation of monitoring wells.

9.6.4 Evaluation of Reservoir Pressure

During the PISC phase, the computational modeling predicts that the pressure in the Mt. Simon Sandstone will steadily decrease toward the pre-injection static pressure. One of the primary forces driving CO_2 or brine migration out of the storage formation is a pressure increase in the storage formation. Figure 9-1 illustrates the rapid decrease in pressure back to pre-injection levels in the Mt. Simon Sandstone once the injection phase of the project ends; and pressure decline toward pre-injection levels is one factor indicative of USDW non-endangerment.

The project will monitor pressure in the Mt. Simon Sandstone in the MCI MW 2 well and at the top of the Mt. Simon Sandstone in the MCI CCS 3 well with downhole pressure gauges (Table 9-6). The measured pressure will be compared to the pressure predicted by the computational model at the same depth. Agreement between the actual and the predicted values will help validate the accuracy of the model and further demonstrate non-endangerment.

9.6.5 Evaluation of CO_2 Plume

During the injection and PISC phases of the project, the extent of the CO_2 plume will be evaluated by PNC logging in the MCI MW 2 well and time-lapse 3D surface seismic surveys.

PNC logging will be used to monitor the distribution and saturation of CO_2 adjacent to the wellbore in the MCI MW 2 well. The PNC logging results can be compared against the model's predicted plume vertical extent at a specific point location at a specified time interval. A good correlation between the two data sets will help provide strong evidence in validating the model's ability to model the CO_2 plume. Time-lapse 3D surface seismic data will be acquired at longer time intervals to track the development of the CO_2 plume over a larger spatial extent. Both data types will be used to verify the computational model's ability to predict the CO_2 behavior in the PISC phase of the project and support a demonstration of non-endangerment of USDWs at the end of the project.

9.6.6 Evaluation of Emergencies or Other Events

Mobilized brine from the storage formation may also pose a risk to USDWs. The geochemical data collected from the MCI ACZ 1 well will be used to demonstrate that the storage formation fluids have not migrated above the confining formation during the injection or PISC phases of the project. If these fluids have not migrated beyond the confining zone during the injection or PISC phases of the project, then they are not anticipated to pose a risk to USDWs after the PISC phase. To demonstrate non-endangerment, results of the fluid sampling in the deepest USDW from the injection and PISC phases will be compared to the pre-injection baseline samples. This comparison will support a demonstration that no significant changes in the fluid properties of the overlying formations have occurred and that storage formation fluids have not moved through the confining layer, and therefore the CO_2 and/or brine would not represent an endangerment to any USDWs.

Section 9.4.6 describes the quality of the well construction for the wells that penetrate the confining zone for this project. The Well Construction Plan and the Well Plugging Plan are presented in Permit Sections 4 and 8, respectively. No other wells penetrate the confining zone within the AoR.

9.7 Site Closure Plan

Marquis Carbon Injection LLC will conduct site closure activities to meet the requirements of 40 CFR 146.93(e) as described below. Marquis Carbon Injection LLC will submit a final Site Closure Plan and notify the permitting agency at least 120 days prior of its intent to close the site. Once the permitting agency has approved closure of the site, Marquis Carbon Injection LLC will plug or transfer to another permit the MCI MW 1, MCI MW 2, and MCI ACZ 1 wells and submit a site closure report to EPA. The activities, as described below, represent the planned activities based on information provided to EPA. The actual site closure plan may employ different methods and procedures. A final Site Closure Plan will be submitted to the UIC Director for approval with the notification of the intent to close the site.

9.7.1 Plugging Monitoring Wells

Prior to plugging the wells, the external integrity of each well will be confirmed by running a temperature log over the entire length of the casing (total depth [TD] to surface). The temperature log will be acquired just before plugging the well and will be compared to previously run temperature logs to ensure that no deflections have developed that may indicate a problem with external well integrity. In addition, PNC logs will be run in the wells following the injection period to confirm that CO_2 has not migrated out of the injection zone.

The Well Plugging Plan for the MCI CCS 3 well can be found in Permit Section 8. The same approach that was used to plug the MCI CCS 3 well will be used to plug the MCI MW 1, MCI MW 2, and MCI ACZ 1 wells. Plugging and abandonment of the MCI MW 1, MCI MW 2, and MCI ACZ 1 wells will meet all requirements set forth by the Class VI regulations. The perforated zone of the well will be plugged using a retainer method and the upper portions of the well will be cemented with a balance method. In addition, the portion of the casing within the storage formation in the deep MCI MW 2 well will be plugged using CO_2-resistant cement. All the wells will have the casing cut off 5 ft below grade and a steel cap will be welded to the top of the deep casing string. The cap will have the well identification (ID) number and the date of plugging and abandonment inscribed on it. The following provides a detailed plan for plugging the MCI MW 1, MCI MW 2, and MCI ACZ 1 wells at the Marquis BioCarbon Project site.

1. Conduct and document a safety meeting.
2. Move-in (MI) rig and ancillary equipment onto well site and rig up (RU). Nipple up and test blow out preventors (BOPs), pressure test equipment and ensure proper operation.
3. Check wellhead tubing and casing pressures.
4. Record bottom-hole pressure from downhole gauge (if final pressure has not already been determined) and calculate kill fluid density.
5. Fill tubing with kill weight brine as determined by the final pressure measurement. Inject two tubing volumes of kill weight brine. Monitor tubing and casing pressure for 1 hour.
6. If the well is not dead or the pressure cannot be bled off the tubing, rig up slickline and set plug in lower profile nipple below packer. Unstab the tubing and circulate tubing and annulus with kill weight fluid until well is dead.

7. Release packer and pull out of hole with tubing laying it down. NOTE: Ensure that the well is over-balanced so there is no backflow due to formation pressure and there are always at least two well control barriers in place.
8. Trip into hole with work string with 5-1/2-inch cement retainer to approximately 100 ft above the top perforation, set retainer to cement the perforated portion of the well, and prepare for cement plugging operations. Pump the specified number of sacks of cement through the retainer while maintaining bottom-hole pressure below fracture pressure. If it appears that the injection pressure will exceed the fracture pressure and the total amount of cement has not been pumped into the injection zone, cement pumping will cease. After allowing the pressure to reduce to an acceptable level, cement pumping will be attempted again. A rapid increase in pressure on the tubing would indicate that the perforations have been sealed with cement, and no additional cement will be added to the zone or plug.
9. If a second perforated zone is present in the well, repeat Step 8 for upper perforated zone.
10. Trip tubing string out of well and remove stinger from end of tubing.
11. Trip tubing string to a depth of approximately 300 ft and prepare to set second cement plug. Pump 12 sacks of Class A cement (slurry weight of 15.9 pounds per gallon [lb/gal]) using a balance method to cement between a depth of 200 and 300 ft.
12. Trip tubing string to a depth of 100 ft and prepare to set third cement plug. Pump approximately 12 sacks of Class A cement to fill the casing from a depth of 100 ft to near surface.
13. Cut the casing string off at 5 ft below grade and weld a steel plate, (with well ID, permit number, and date of abandonment on it) to the casing strings.
14. Backfill the excavation.
15. Rig down and move off service rig and any remaining equipment.

Tables 9-7 and 9-8 provide the methods that will be used to set the plugs in each of the monitoring wells, and Tables 9-9 and 9-10 provide the materials that will be used during the plugging process. The volume of the casing to be cemented was calculated using the inside diameter of the 5-1/2-inch casing string (4.892 inches), and the length of the casing to be cemented. Note that an additional 10% volume was used when calculating the cement needed to cement the perforated zones.

Zone of Interest	Cemented Depth (ft, MD)	Formation	Plugging Method	Plug Description	
				Type	Quantity
Perforated Interval	Various between 3,165–4,050	Mt. Simon Sandstone	Retainer	CO_2-Resistant	132 sacks
5-1/2-in. Casing Column	200-300	Pennsylvanian	Balance	Class A	12 sacks
5-1/2-in. Casing Column	0-100	Pleistocene Drift	Balance	Class A	12 sacks

Table 9-7: Intervals to be plugged and methods used when plugging the MCI MW 2 well.

Zone of Interest	Cemented Depth (ft, MD)	Formation	Plugging Method	Plug Description	
				Type	Quantity
Galesville Perforated Interval	2,425-2,595	Galesville Sandstone	Retainer	Class A	37 sacks
Deepest USDW Interval	1,337-1,482	Deepest USDW	Retainer	Class A	33 sacks
5-1/2-in. Casing Column	200-300	Pennsylvanian	Balance	Class A	12 sacks
5-1/2-in. Casing Column	0-100	Pleistocene Drift	Balance	Class A	12 sacks

Table 9-8: Intervals to be plugged and methods used when plugging the MCI ACZ 1 well.

Plug Information	Plug #1	Plug #2	Plug #3
Diameter of boring in which plug will be placed (in.)	4.892	4.892	4.892
Depth to bottom of tubing or drill pipe (ft, MD)	3,065	300	100
Sacks of cement to be used (each plug)	132	12	12
Slurry volume to be pumped (ft^3)	142	13.1	13.1
Slurry weight (lb./gal)	15.2	15.9	15.9
Slurry Yield (ft^3/sack)	1.07	1.18	1.18
Calculated top of plug (ft, MD)	3,065	200	0
Bottom of plug (ft, MD)	4,050	300	100
Type of cement or other material	CO_2- Resistant	Class A	Class A
Method of emplacement (e.g., balance method, retainer method, or two-plug method)	Retainer	Balance	Balance

Table 9-9: Materials used for plugging the MCI MW 1 well.

Following the plugging and abandonment of the monitoring wells, the above ground infrastructure, such as wellheads, monitoring equipment, etc., will be removed, and the area around the wells will be regraded to follow the natural topography of the surrounding area (currently agricultural fields). The ground will be replanted with either native vegetation or be converted back to agricultural land.

Plug Information	Plug #1	Plug#2	Plug #3	Plug #4
Diameter of boring in which plug will be placed (in.)	4.892	4.892	4.892	4.892
Depth to bottom of tubing or drill pipe (ft)	2,325	1,237	300	100
Sacks of cement to be used (each plug)	37	33	12	12
Slurry volume to be pumped (ft^3)	39	35.2	13.1	13.1
Slurry weight (lb./gal)	15.2	15.2	15.9	15.9
Slurry Yield (ft^3/sack)	1.07	1.07	1.18	1.18
Calculated top of plug (ft)	2,325	1,237	200	0
Bottom of plug (ft)	2,595	1,482	300	100
Type of cement or other material	CO_2-Resistant	CO_2-Resistant	Class A	Class A
Method of emplacement (e.g., balance method, retainer method, or two-plug method)	Retainer	Retainer	Balance	Balance

Table 9-2: Materials used for plugging the MCI ACZ 1 well.

9.7.2 Site Closure Report

A site closure report will be prepared and submitted within 90 days following site closure, documenting the following:

- Plugging of the monitoring wells (and the MCI CCS 3 well if it has not previously been plugged)
- Location of sealed MCI CCS 3 well on a plat of survey that has been submitted to the local zoning authority
- Notifications to state and local authorities as required by 40 CFR 146.93(f)(2)
- Records regarding the nature, composition, and volume of the injected CO_2, and post-injection monitoring records.
- Groundwater monitoring wells may be converted to use as groundwater wells as appropriate.

Marquis Carbon Injection LLC will record a notation to the property's deed on which the MCI CCS 3 well was located that will indicate the following:

- That the property was used for CO_2 sequestration
- The name of the local agency to which a plat of survey with MCI CCS 3 well location was submitted
- The volume of fluid injected
- The formation into which the fluid was injected, and the period over which the injection occurred.

The site closure report will be submitted to the permitting agency and maintained by the owner or operator for a period of 10 years following site closure. Additionally, the owner or operator will maintain the records collected during the post-injection period for a period of 10 years after which these records will be delivered to the UIC Director.

9.7.3 Quality Assurance and Surveillance Plan (QASP)

The QASP is presented in the Appendix A of the Testing and Monitoring Plan (Permit Section 7.0).

References

Enick RM, Klara SM. CO_2 solubility in water and brine under reservoir conditions. Chemical Engineering Communications 90(1):23-33 (1990).

FutureGen Alliance, 2013, Underground Injection Control Permit Applications for FutureGen 2.0 Morgan County Class VI UIC Wells 1, 2, 3, and 4, FG-RPT-017.

Golden StrataServices, 1984, Jones & Laughlin Steel Inc, Hennepin Illinois, UIC Permit Application, UIC-004-WI-JL, EPA Facility ID No. ILD000781591.

Land CS. Calculation of imbibition relative permeability for two-and three-phase flow from rock properties. Society of Petroleum Engineers Journal 8(02):149-56 (1968).

Li YK, Nghiem LX. Phase equilibria of oil, gas and water/brine mixtures from a cubic equation of state and Henry's law. The Canadian Journal of Chemical Engineering 64(3):486-96(1986).

Nghiem L, Shrivastava V, Tran D, Kohse B, Hassam M, Yang C. Simulation of CO_2 storage in saline aquifers. In: SPE/EAGE Reservoir Characterization & Simulation Conference: European Association of Geoscientists & Engineers. p. cp-170-00063 (2009).

Raziperchikolaee S, Alvarado V, Yin S. Effect of hydraulic fracturing on long-term storage of CO_2 in stimulated saline aquifers. Applied energy 102:1091-104 (2013).